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Effect of Exhaust Gas Recirculation (EGR) on Diesel Engine Oil – impact on wear

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Background

- Exhaust gas recirculation (EGR) is an effective means to reduce NOx emission from diesel engine

- EGR will contaminate engine oil
  - Increase of oil soot loading
  - Increase in oil total acid number (TAN)

- EGR will result in durability problem for many lubricated engine components due to accelerated wear

- Goal: Mitigate detrimental impact of EGR on engine components through materials, surface and lubricant technologies.

Approach

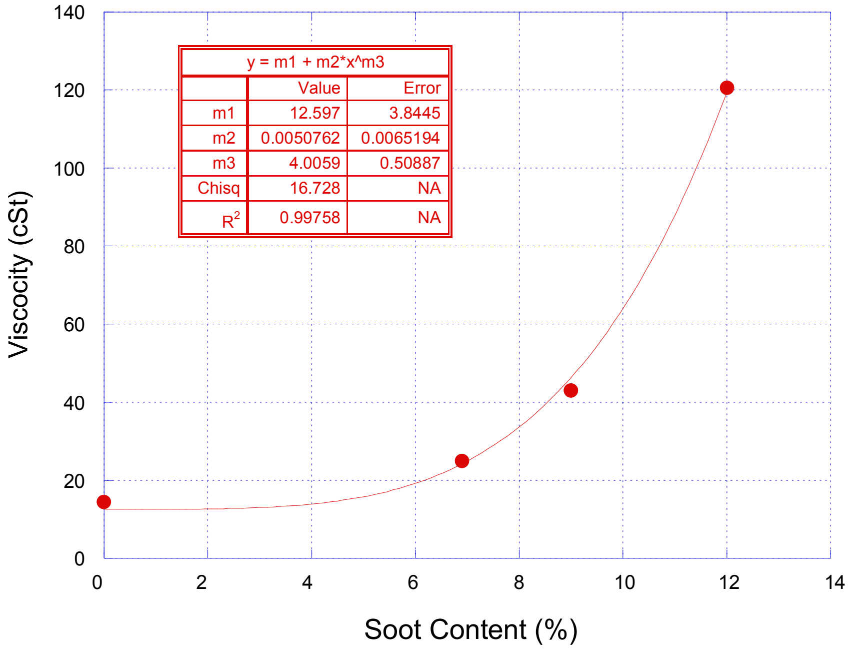
- Characterize and quantify effect of EGR on lubricant degradation
  - Physical, chemical, etc.
- Evaluate impact of lubricant degradation on friction and wear behavior
- Develop and evaluate material and surface technologies for improved friction and wear performance in EGR environment
- Develop and evaluate advanced lubricant formulation for EGR
  - Impact of regulation

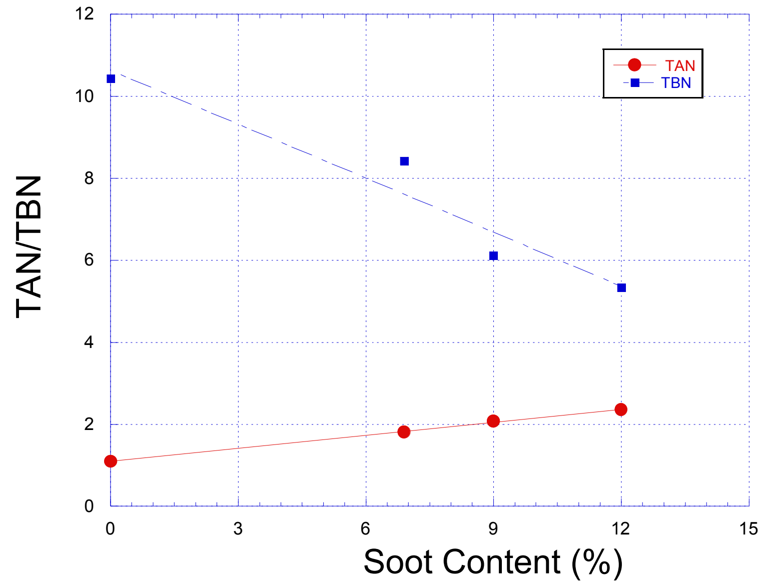
Oil Degradation – physical

- Used oils from Cummins M-11 engine tests were characterized

	A (New oil)	B	C	D
Viscosity at 100 °C (cSt) (start of engine test)	14.40	14.39	14.55	14.86
Viscosity at 100 °C (cSt) (end of engine test)	-	24.95	42.91	120.52
Total Acid Number (TAN)	1.1	3.81	2.08	2.36
Total Base Number (TBN)	10.43	8.42	6.11	5.33
Soot Content (%)	0	6.9	9.0	12.0

Oil Degradation





- ➢ Oil viscosity increases as 4th power of soot content.
- ➢ Oxidation may also contribute to oil thickening.
- ➢ Soot content of 4.5% limit in engine tests.

- ❖ TAN and TBN variation as expected.
- ❖ Non of used oils reached cross over point.

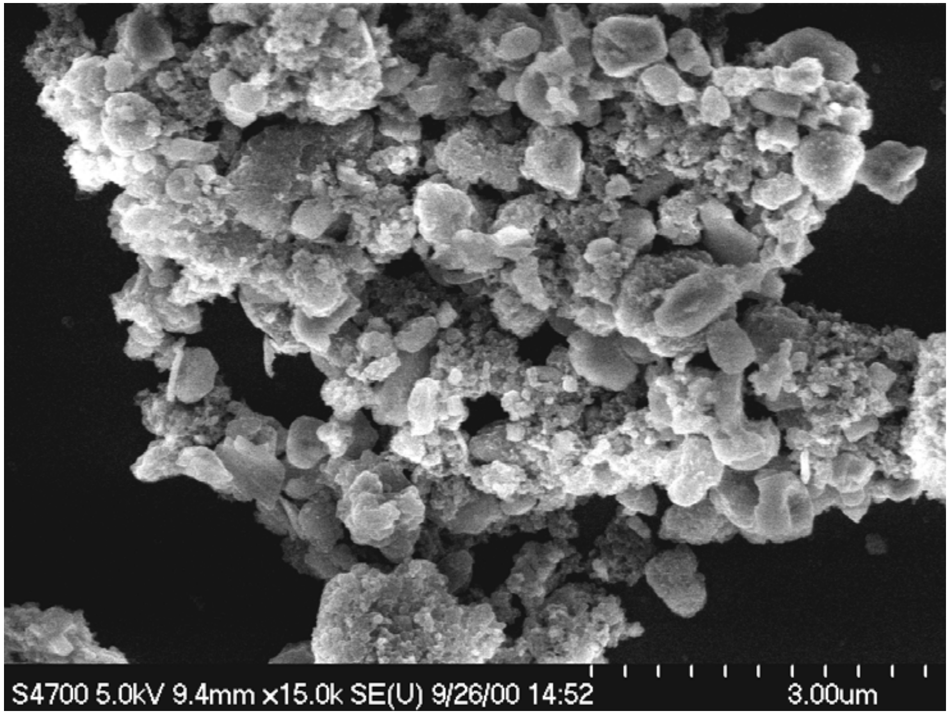
Oil Degradation – Additives

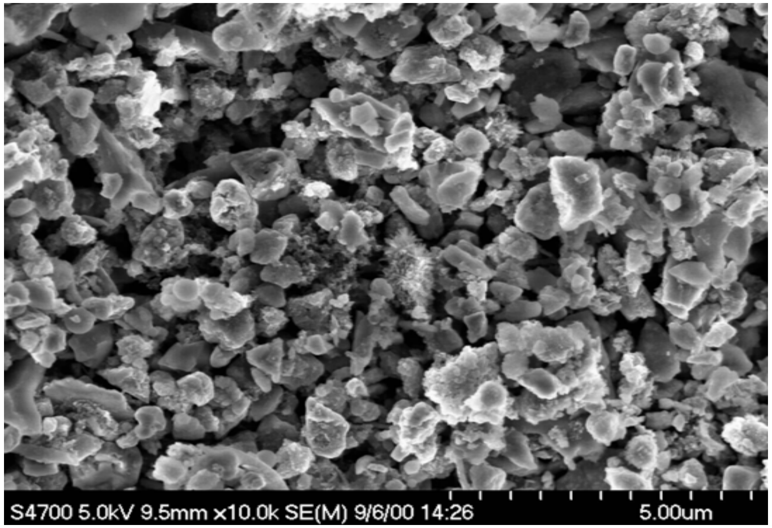
- Used oils from Cummins M-11 engine tests chemical composition (ppm) characterized by standard spectrochemical analysis

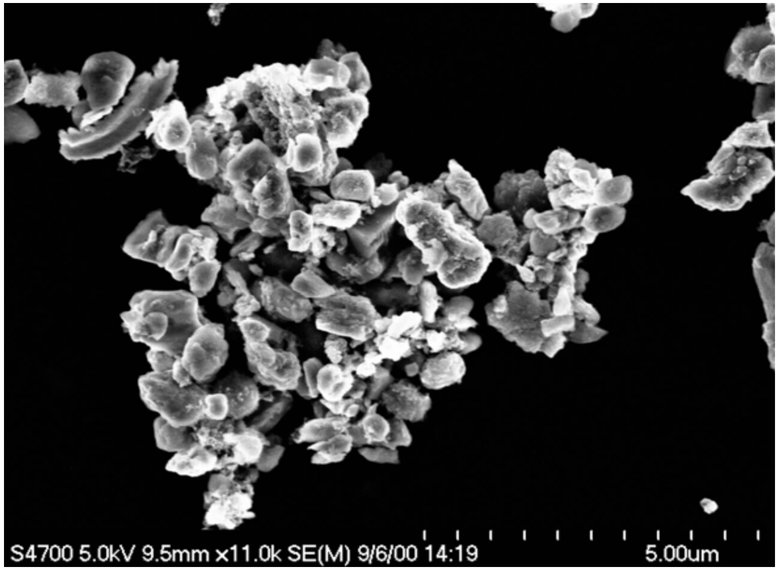
Element	A (New oil)	B	C	D
Iron (Fe)	1	119	147	58
Chromium (Cr)	< 1	18	25	10
Molybdenum (Mo)	< 5	6	< 5	< 5
Phosphorus (P)	1247	750	756	304
Zinc (Zn)	1356	1111	945	843
Calcium (Ca)	3992	1096	3058	999
Magnesium (Mg)	14	10	10	4

- Increase iron content from wear
- Decrease in additive content – additive depletion

Soot (Solid) Particles







- ❑ Insoluble solid particles in used oil consist of many components.
  - Carbon, iron oxide, metallic wear debris

- ❑ Variety of sizes and shapes

Preliminary Friction and Wear Test

Test configuration:
Four-ball (ASTM D 4172)

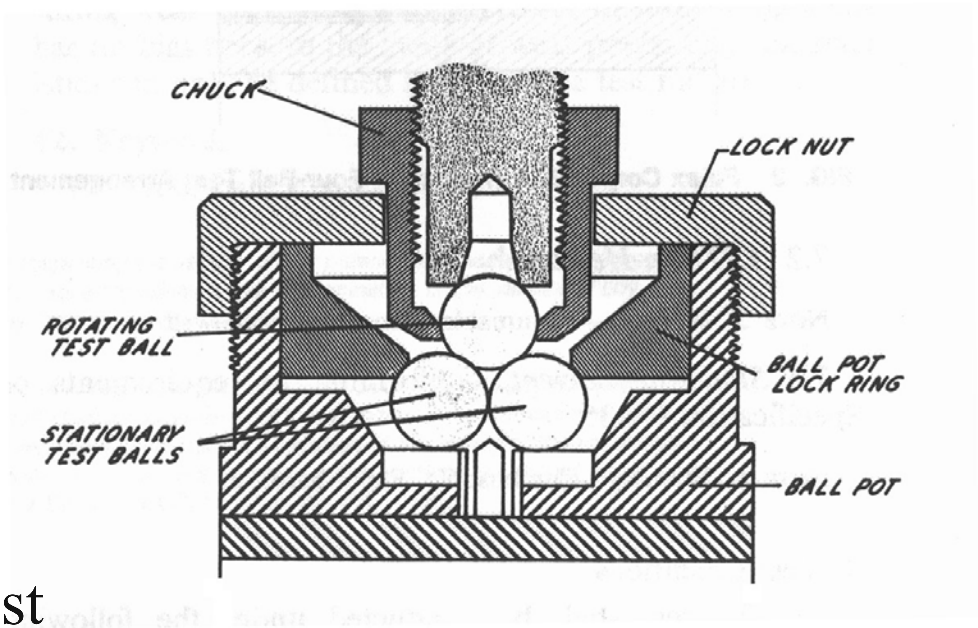
Balls: ½" diameter M50 steel

Load: 73 N

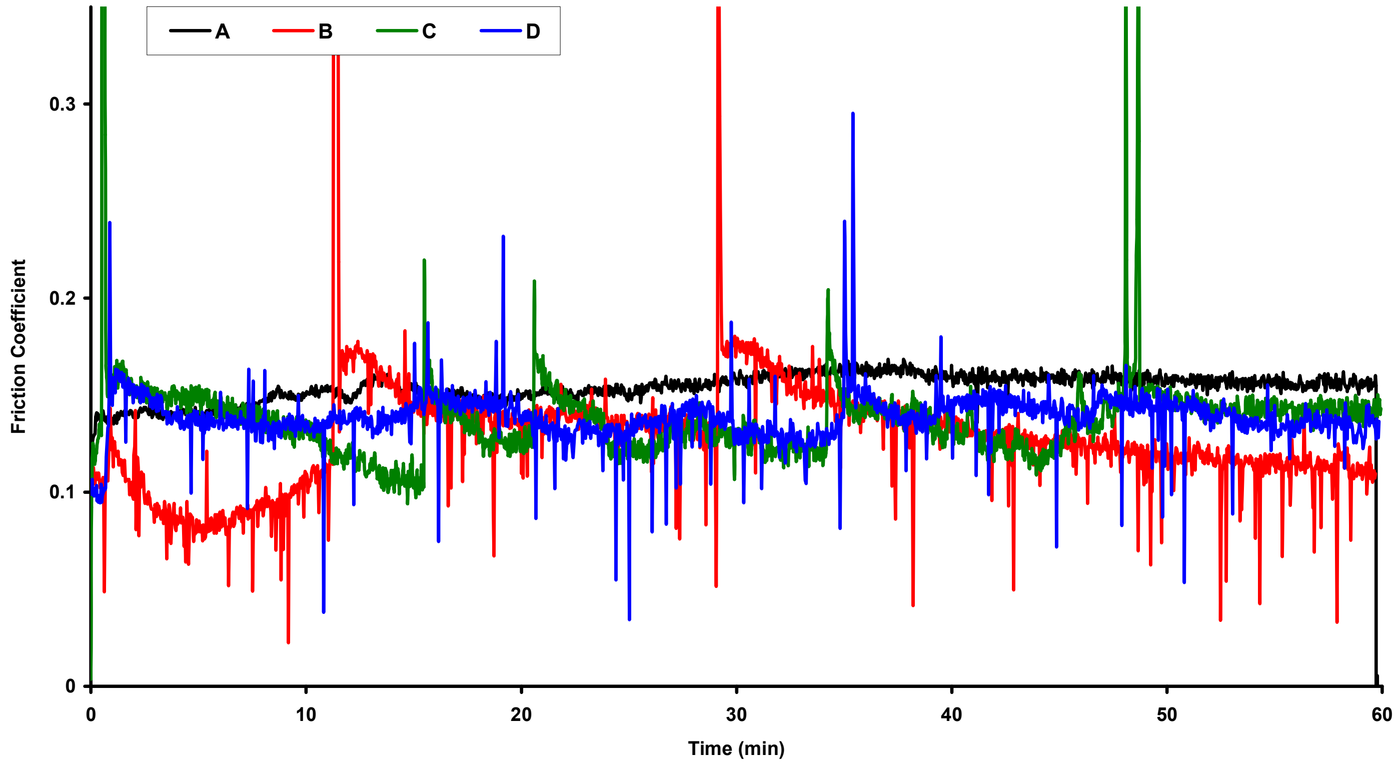
Speed: 1200 rpm

Lubricant: New and used oil from Cummins M-11 engine test

Duration: 1 hour



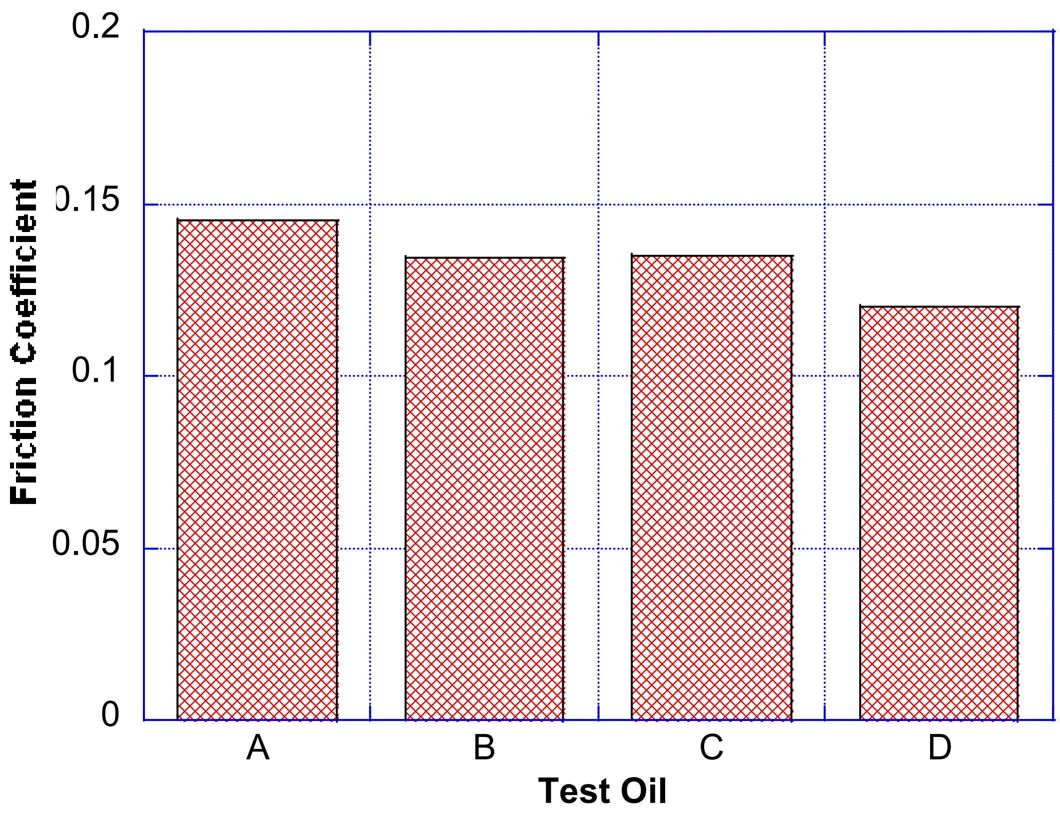
Friction Results



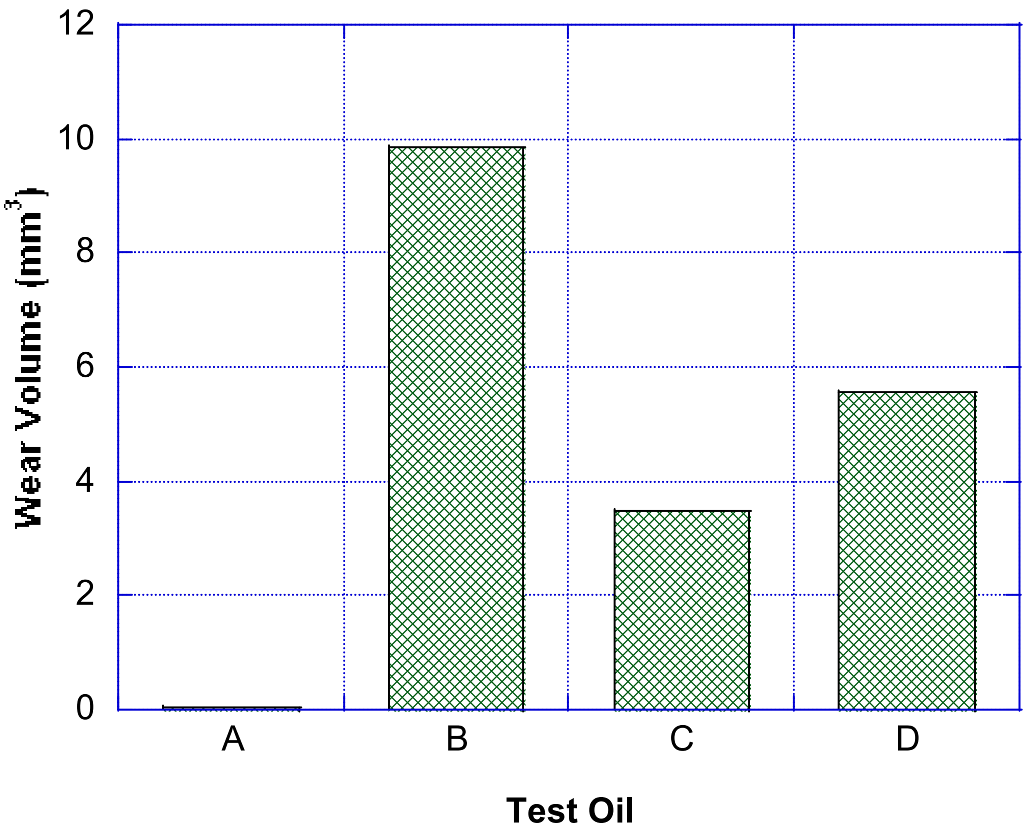
- Friction coefficient nearly constant for duration of test for all oils
- Periodic spike in friction for all the used oils

Friction Results

- Average friction for used oil slightly lower than for clean oil
  - Effect of viscosity increase on fluid film
  - Carbon soot acting as solid lubricant

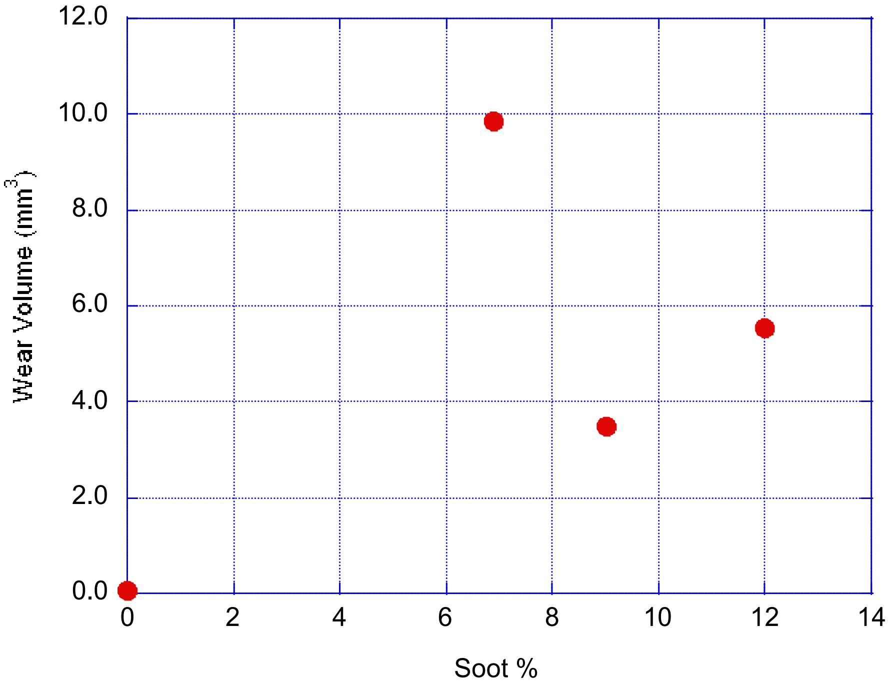


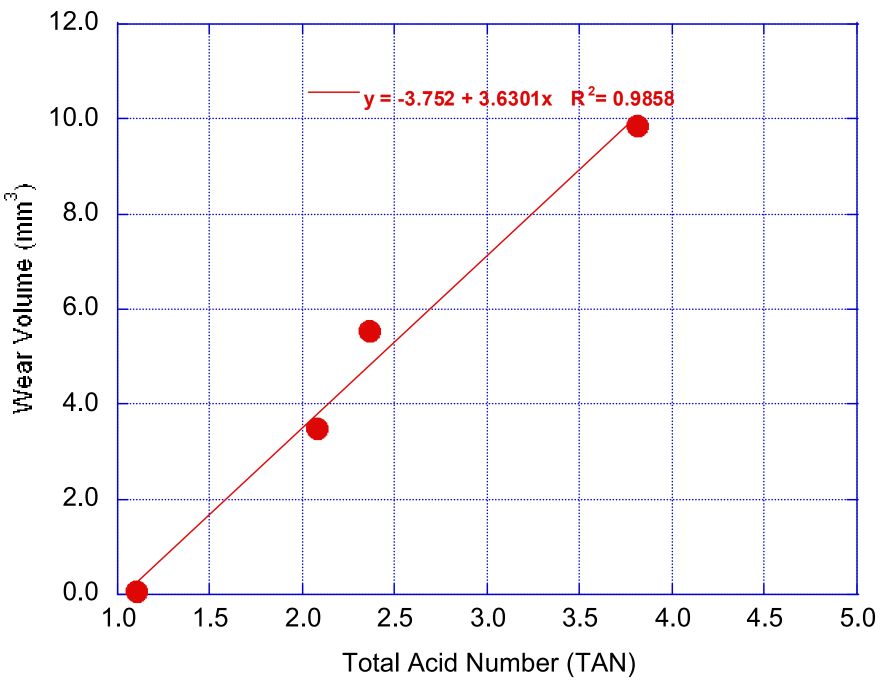
Wear Results



- Substantial increase in wear in tests with used oils
  - Oil degradation leads to less protection of rubbing surfaces
    - *Change in chemistry*
    - *Presence of solid particles*

Wear Results

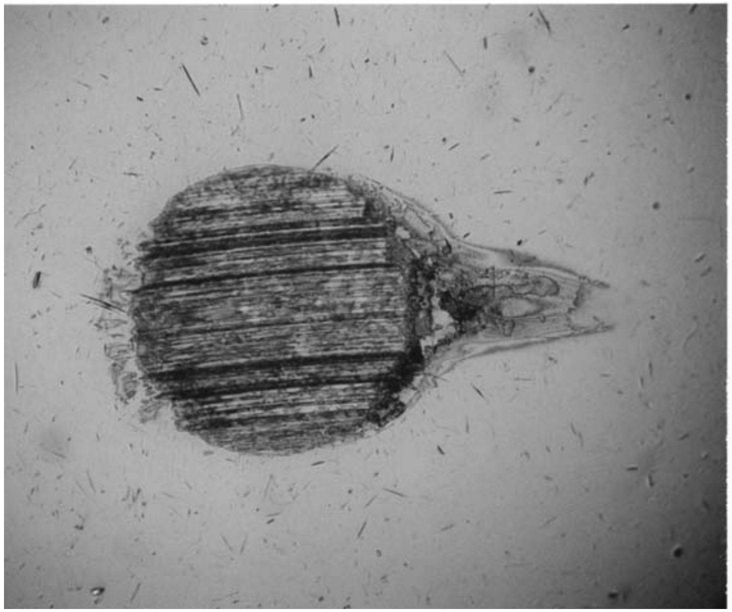


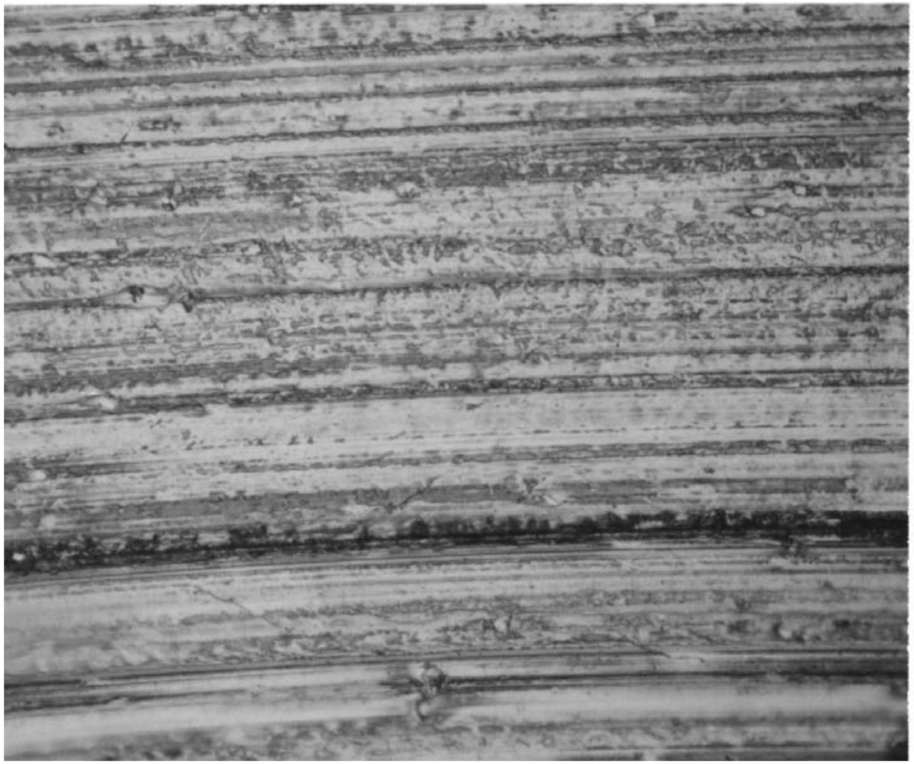


For the limited data points in the present study

- Wear volume not dependent on soot content
- Wear appears linearly dependent on TAN

Wear Mechanism – *clean oil*

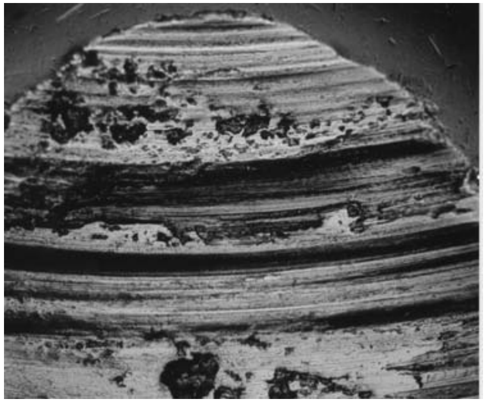




- Evidence of abrasive and oxidative wear
- Formation of surface films – reaction with lubricant additive

Wear Mechanisms – used oil

Oils B & C



Oil D

- For used oils B and C, wear similar – primarily abrasive, with less surface films
- For used oil D, in addition to abrasion, evidence of corrosion and scuffing
  - Higher TAN (corrosion) and soot content (scuffing).
  - Soot interferes with lubricant entrainment into the contact

Conclusions

- Exposure of oil to EGR during diesel engine testing resulted in accelerated degradation of oil
  - Increase in soot content resulting in significant increase in oil viscosity
  - Increase TAN and more rapid decrease in TBN
  - Oil additive depletion

- Although the used oil reduced the average friction during a four-ball bench-top test, wear was increased by about two orders of magnitude compared to new oil.

- In the tests with used oils, predominant wear mode is abrasion, aided by corrosion.
  - Scuffing was also observed in test with 12% soot content.

- No clear trend correlation can be established between bench-top friction and wear testing and wear during engine test.

The End

- Thank you !

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